Rigidizing Deployable Structures in the Micro-Strain Regime
Notes to Augment the Presentation Charts

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The idea behind adhesively bonded latch joints derived from experience with lightweight space telescopes where positional certainty of the joints and a strain-free structure were critically important to achieving alignment mechanical stability in the optically significant micro to nano-strain regime. The Hubble Space Telescope secondary mirror support truss is an early example of this approach. This 5m long, 2.6m diameter and 100 kg composite structure was comprised of 48 struts and three rings and was assembled by adhesive bonding in a strain free “weightless” condition where no member was loaded by more than its own weight, or in the case of the rings, only a fraction of its own weight during the assembly operation. The bonded connections offered no possibility of joint instability or multi-equilibrium positional states and the structure, devoid of internal strain, provided no potential for loading these joints as well. This cautious approach flew in the face of mid-1970’s conventional wisdom when (the fledging) composite designs were often bolted and pinned together via mechanical end fittings. The HST design was driven by the then challenging requirements to maintain the positional stability of the secondary mirror to about 1 micron for any 24 hour period, during which the telescope would be slewed from one viewing orientation to another and experience large thermal changes. These joints provided mechanical and CTE continuity from one end of the structure to the other and provided margin for the myriad of other factors, “lurking in the woodwork”, that could despace or decenter the mirror. In addition to slowly varying thermal effects on alignment stability, the possible ‘spontaneous’ release of any entrapped strain energy in the structure, from assembly fit-up tolerances or gravity release, caused by slew accelerations or non-linear thermal gradients (etc.) was also a concern. If one of the forty eight 1.8m long struts was installed in a near-buckled condition (the rubber mallet method of parts fit-up as practiced in some welding shops!) was caused to buckle by the addition of external energy (from a slew, perhaps), the structure would experience an instantaneous global shape change. It also might vibrate a bit, although practically it damped out rapidly by the cables and MLI that seem to ‘contaminate’ the pristine structures we all envision. When that structure was developed in 1975, the tools weren’t available to rigorously investigate this ‘release of entrapped strain energy’ issue and only very primitive models, like the one shown on Chart 6, “Why Strain-Free Assembly” were available to provide design guidance.

But HST’s micron-level tolerances were easy compared to the demands on alignment stability and jitter limits imposed by today’s and tomorrow’s larger and lighter systems where segmented primary mirrors might demand 25 nm, (four thousandth the thickness of a sheet of paper) jitter stability from petal-to-petal as suggested on Charts 7 and 9.While image jitter caused by SM vibration can be negated with a small steering mirror near the detectors, the effect on MTF or wavefront quality is not correctable with current or near-envisioned technology. It represents an indeterminate sensing problem at the image and a nearly impossible correction problem, if a sensing scheme were even able to generate the necessary commands. Better not to let the petals vibrate!

So putting the demanding alignment and jitter stability requirements for deployable segmented mirrors together with the idea of joint continuity, the avoidance of entrapped assembly strains and assured positional certainty, the idea for adhesively bonded latch connections was originated. Our goal is to emulate the Chevrolet Blazer adverts that proclaim their vehicle to be… "Like a Rock" and to avoid the kinds of problems listed on Chart 4, " Potential Problems with Deployment Latches".

Replacing mechanical latches with automatically activated adhesively bonded connections is at present an emerging concept, far from a 'ready-to-go' technology. However a specific application of the idea is being developed for the DOT (Deployable Optical Telescope) experiment at the AFRL in Albuquerque headed by Col. M. Powers and is illustrated, at least conceptually in the attached charts which are intended to be largely self-explanatory. As the charts show, the idea of bonded-in-space connections or joints can be utilized in one of two different ways, depending on the geometry and the function of the connection itself. One is for primary loadpaths where adequate shear area is available, the loads are relatively low, and the geometry is compatible with the application of the adhesive. The second is to 'rigidize' a rotary mechanical connection like a journal pivot by injected a thixotropic epoxy into a series of recesses to essentially "freeze" the connection. This would be a secondary or parallel load path. It has the same function as rust for those of you who might have attempted to disassemble an antique car as part of the restoration process!

The paper illustrates several joint concepts configured for both primary and secondary load path applications using heat-activated dry film adhesives and two-part epoxy "gap fillers" respectively. For these joints to be successful, the following basic "design rules" apply:

a) the pre-cured adhesive should be capable of long duration vacuum exposure and still be capable of being activated
b) any organic outgassing products resulting from the cure should be negligibly small or contained to prevent optics contamination
c) during curing, the parts must be held in a positionally stable condition with the correct pressure across the bondline and configured so that the desired bondline geometry (thickness and thickness uniformity) is achieved in the presence of real-world deformations, tolerances and related conditions

The "glue shoe" concept shown on Charts 18, and several subsequent, was configured to achieve these conditions by the use of kinematic constraints (pins and lands) for positional certainty during curing and flexures (aka controlled elasticity) to accommodate tolerance build-ups and still ensure the necessary bond-line thickness and clamping pressure.

d) an abbreviated or short cure time is desirable to minimize heater power or clamping pressure power

e) the overall bonded joint design needs to be 100% dependable since it is non-reversible; it can't be activated as part of an acceptance test and then de-energized and activated again in space. It needs to have the dependability of a bullet!
f) the strength of the joint needs to be adequate for the loads and stiffness requirements experienced in the deployed, 0-g conditions. The ultimate strength capability of the adhesive systems may be well in excess of these requirements.
g) …..and so on

In selecting adhesives for these applications, an experimental program to determine under what conditions of pressure, temperature, time and geometry acceptable, "factory-like" bonded connections can be made, and the amount and type of outgassing products resulting from curing or activation, would first be undertaken.

While the "glue shoe" was conceived to be a primary loadpath for applications such as the telescoping cylinders that form the SM support "tower" (see the ITTT/SIRTF telescope for a small-scale application of a 'tower' design), it also might be an alternative to a mechanical latch for a folding petal PM design as shown on Chart 20. Depending on who the designer is, and what day of the week he's doing it, a folding petal might employ a journal pivot like the one illustrated in Charts 20 and 21. As shown there, these pivots also must carry part of the petal assembly load during ascent. For a 4m petal whose areal density is 20 kg/m^2, that means the pivot assembly might see vibratory loads on the order of 3000 lbs which begins to suggest relatively robust bearings (like the front wheels of a car!). Remembering from Chart 9 that a latch or pivot displacement of 10 nm (a ten thousandth of the thickness of the piece of paper that this is printed on!) is about all that can be tolerated, it is prudent then to rigidize this pivot, after it is "beaten up" during ascent, to take up any free-play or whatever that might be equivalent to a 10 nm "clearance". That's the idea behind the "gap-filler" illustrated on Chart 21. This chart is largely self-explanatory but a few words of explanation are in order:

a) the gap filling 'adhesive' is intended only to provide radial stiffness, rotational stiffness is provided by the latch shown on the previous chart
b) the adhesive is mixed in the yet-to-be-defined mixing chamber in the cartridge assembly and constrained to remain with a volume defined by the O-rings (or equivalent seals) and the shaft-to-housing clearances.
c) The volume of adhesive or 'filler material' forced into the above annulus is nominally equal to the annulus volume to prevent it from "squirting out" although if it does "squirt", it would be inwards as inferred by the single O-ring.

Engineering development tests like the one depicted on Chart 22, utilizing the Raytheon Systems Company's "Strut Tester" would be conducted as part of development program. A chart summarizing what the strut tester does is included for those who are unfamiliar with the apparatus, or who have not yet heard Roman Hachkowski's paper.

This about sums up the bonded-in-place construction concept for large deployable telescopes that I had hoped to present at this conference. However last minute schedule conflicts prevented me from attending and therefore these notes were rather hastily put together to explain the ideas behind the charts. I can be reached at 203 261 8624 or at the Internet address at the beginning of this note for questions or comments.